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(54) Speed sensorless variable voltage variable frequency induction motor drive.

(57) During motor jerk-out, the real component of a stator current ReI is measured (20) as an approximation to torque current I_T, and a reference acceleration A_{ref} is obtained as an approximation to the motor acceleration, for providing, by means of linear regression (22), the Y intercept of a line defining the relationship between ReI and A_{ref}, which intercept defines ReI at a constant high speed ($ReI_{CONSTANT\ HIGH\ SPEED}$), for linearly relating (24) $ReI_{CONSTANT\ HIGH\ SPEED}$ to a compensation frequency f_{comp} which is provided to a summer (4) for summing f_{comp} with a reference. frequency f_{ref} used for dictating motor (13) speed. The stator current I and A_{ref} are sampled during jerk-out when the motor is at high speed because there the real component of the stator current ReI is approximately equal to I_T.

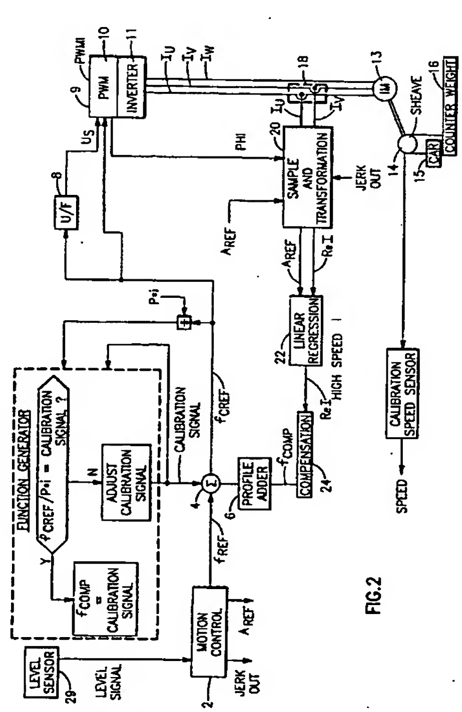

FIG.2

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This invention relates to a variable voltage variable frequency induction motor drive without speed feedback, e.g. for an elevator.

Variable speed induction motor drives using static inverters are widely used. When dynamic performance is not important, the speed of the motor drive is simply adjusted by changing the frequency of the input while keeping the voltage-hertz ratio constant. There are situations, however, requiring fast response, for instance, in servo-applications. Then, feedback from speed information from the rotating shaft of the machine is usually required. Such feedback is part of a closed loop for control, or it may be part of the torque control algorithm for the determination of the slip frequency (or simply slip) of the motor excitation. In such instances, a tachometer or a high-resolution encoder is typically mounted on the motor shaft in order to provide such feedback. Often, however, the output of a tachometer includes ripples and a special tachometer which eliminates ripple must be used if the ripple is unacceptable. Such a tachometer is described in U.S. Patent No. 4,520,300 "Brushless Ultra-efficient Regenerative Servomechanism."

High performance speed control, where it is uneconomical or impractical to have a shaft mounted transducer is desirable. This is the case with linear motor driven transportation systems or with steel mill drives because transducer cabling is undesirable in an environment which is inhospitable around the motor. It is also the case with retrofit applications where an existing induction motor having no shaft transducer installed needs to be speed controlled. Operating a motor without speed feedback can, however, result in motor tilling. That is, as the motor nears its stopping point and a given creeping speed is desired to be commanded for the motor, too low a creep speed is commanded, because the actual speed of the motor is not known, and the motor reverses its direction.

Speed sensorless induction motor control is known. See, for example, U.S. Patent No. 4,009,427 by Takahashi and U.S. Patent Nos. 4,530,376 and 4,680,526, both by Okuyama, and "Speed Compensation Motor Circuit Utilizing Real Current Component" U.S. Pat.No. 3,619,750.

Model reference adaptive control has been described in "Adaptive Control - The Mono-Reference Approach" by Yoan D. Landau, published by Marcel Dekker, Inc., New York 1979. It is known to identify the speed of an inverter-fed induction motor by the technique of model reference adaptive control. See, for example, "Speed Sensorless Vector Control of Induction Motor with Mono-Reference Adaptive System" by Shinzo Tamai, Hidehiko Sugimoto, and Masao Yano, on pages 189-195, a paper print presented at an IEEE Conference in Atlanta, Georgia on 18-23 October 1987, IA Vol. 1.

Other articles of interest are: (1) "Observers for Flux Estimation in Induction Machines" by George C. Verghese and Seth R. Sanders, IEEE trans. Industrial Electronics, Vol. 35, No. 1, for February 1988, pages 85-94; (2) "Vector Control System for Induction Motor using a Speed Estimation Based on Instantaneous Slip Frequency Principles", by Hirotami Nakano, Shinichi Horie, Tsuyoshi Matsuo, and Kohji Iwata, pages 95-103, Electrical Engineering in Japan, Vol. 107, No. 4, 1987.

Another speed sensorless system is shown in "Tacho-less Vector Control Adaptive System from Motor Drive" by Schauder, U.S. Patent 4,862,054, which shows a reference model based on the model equation of an asynchronous motor combined with an adjustable model responsive to the direct in quadrature components of the current and to an estimated speed. An adaptive mechanism counting in a P-I amplifier expands to the direct deviation between the direct in quadrature components and generates a feedback signal representing the estimated speed. The adjustable model reacts to the estimated speed signal.

Japanese Application No. 57-71295, "Speed Controller for Induction Motor", shows a speed control without a speed detector by employing a double control loop with a slip angular frequency arithmetic unit and an overshoot and prevention circuit as a feedback system for speed controlling and frequency controlling amplifiers. And, Japanese Application No. 57-142188 "Controlling Device for Commutatorless Motor", shows a controlling device for a highly efficient commutatorless motor without necessity of a speed detector by controlling the prescribed gamma constantly by using a synchronizing signal from a distributor without producing an actual speed signal. And, Japanese Application No. 1-114394, "High-performance Speed Controlling Circuit for Multiphase Induction Motor based on Detection of Only Current" shows an industrial motor control without a speed detecting device, by detecting motor current only and by computing the slip angle speed of the space vector of magnetic flux

Still another speed sensorless drive, "Speed Control System for Elevators", U.S. Patent No. 4,982,816 shows an elevator with an induction motor drive wherein the output torque is determined by direct current of an inverter, slip frequency is determined from the torque, the gap between an open-loop dictated speed pattern and the actual speed is compensated by the slip calculated during acceleration and constant speed movement so that the open-loop control may be improved in terms of stop position precision.

The goals of the present invention are to minimize speed error in the creep region of an elevator motor by estimating slip (the creep region is the constant speed region of a motor immediately prior to its stop point, where fine positioning of the elevator near a floor is important), provide enough motor torque

(since slip frequency is proportional to torque) to prevent motor tilling, and position accurately the motor near its stopping point without using a speed sensor.

Viewed from one aspect, the present invention provides a method of compensating for a difference between a reference frequency proportional to a dictated motor speed and actual motor speed in an open loop three phase asynchronous motor drive, comprising:

providing a reference acceleration signal during motor jerk out;

measuring the real component of a stator current;

obtaining a constant speed value from the real component of the stator current; and

providing a compensation frequency which is a function of the constant speed value; and

adding said compensation frequency to said reference frequency.

Viewed from another aspect, the present invention provides a speed compensator for an open loop asynchronous motor drive responsive to a reference frequency proportional to a dictated motor speed, comprising:

sample and transformation means for providing the real component of a stator current in response to two phase stator currents and an angle between a stator voltage and a real axis;

linear regression means, responsive to said real component of said stator current for providing a constant speed value of said real component of said stator current;

compensation means, responsive to said constant speed value for providing a compensation frequency; and

a summer for adding said compensation frequency to said reference frequency.

In an induction motor:

(a) reference frequency f_{ref}, which is proportional to a reference speed, is desired to be equal to motor speed;

(b) slip is proportional to torque current I_T;

(c) the relationship between I_T and acceleration may be described by a linear equation:

$$I_T = I_{T,\text{CONSTANT HIGH SPEED}} + k * \text{acceleration} \quad \text{(equation 1);}$$

(d) at high motor speeds, when the angle between the stator voltage and stator flux is nearly 90 degrees, the real component of the stator current is approximately equal to the torque current I_T.

Because f_{ref} is not equal to the motor speed in actuality,

$$f_{ref} + f_{comp} = f + \text{slip frequency} \quad \text{(equation 2)}$$

where f_{comp} is a compensation frequency for minimizing speed error between the speed commanded by the reference frequency and the speed of an elevator; f = motor speed =stator frequency - slip frequency and is therefore proportional to the speed of the elevator.

Because slip frequency (or simply slip) is proportional to I_T and f_{comp} is proportional to slip, then f_{comp} is proportional to I_T. Finally, because I_T is related to acceleration (equation 1 above), I_T can be determined during jerk-out and the relationship between I_T and f_{comp} can be determined on a calibration run.

The present invention has these advantages:

(a) cost savings of a motor drive with no speed sensor;

(b) speed error compensation in a drive in which a speed sensor cannot be retrofitted;

(c) avoidance of stabilization problems contributed to by ripple in the output of a speed sensor;

(d) providing enough motor torque (since slip frequency is proportional to torque) to prevent motor tilling;

(e) position accuracy near the motor stopping point without using a speed sensor;

(f) reduced time for the motor to complete a run from start to finish by reducing the creep time of the motor, i.e. the time that the motor is running at creep speed; and

(g) the above advantages regardless of whether the motor achieves and maintains a high constant speed.

These and other objects and advantages of the present invention will become more apparent in the light of the detailed description of a preferred embodiment thereof, given by way of example only, as illustrated in the accompanying drawings.

Fig. 1 is a plot of stator voltage U_S v. inverter input frequency, f.

Fig. 2 is a block diagram of a motor control system in acordance with the present invention.

Fig. 3 is a plot of torque current I_T v. ref. acceleration A_{ref}.

Fig. 4 is a plot of reference acceleration A_{ref}, reference f_{ref} frequency, jerk, and actual speed v. time at full load.

Fig. 5 is a vector diagram of stator voltage U_S, torque current, I_T stator current I, and flux.

Fig. 6 is a flow chart for the sampling and transformation means shown in Fig. 5.

Fig. 7 shows a leveling sensor mounted on a car.

Fig. 8 shows torque current I_T at creep speed f_{comp} v. $I_{T,\text{ CONSTANT HIGH SPEED}}$.

Fig. 9 shows acceleration A_{ref}, reference stator frequency f_{ref}, and actual motor speed v. time where f_{comp} is summed with f_{ref} and where f_{comp} is not summed with f_{ref}.

Fig. 1 is a graph of inverter input frequency f v. stator voltage, U_S, for a variable voltage variable frequency induction motor (VVVFIM) connected to a sheave for moving a car and counterweight.

After f reaches about 10% of the nominal inverter input frequency f_N, the relationship between f and the stator voltage, U_S, is linear. The principle of a VVVFIM

is that one can alter the speed of an induction motor (IM) by varying f so long as U_S/f is maintained constant. Where the VVVFIM turns a sheave of a geared elevator, the speed of VVVFIM is related to f by the following equation:

$$\text{speed (m/s)} = 2\Pi \frac{r}{i} \cdot \frac{f}{P}$$

where

r is the radius of the sheave
i is the gear ratio and
2*P is the number of poles.

The advantage of a VVVF controlled IM is that the IM can be controlled as easily as a DC machine. However, varying f does not always result in a proportionate change in motor speed because there may be a speed error-a difference between f and the speed of the car. The goal of the present invention is to compensate for this difference without a speed sensor where it is necessary to ensure sufficient motor torque and position accuracy by using a compensation frequency f_{comp}.

Therefore, to obtain f_{comp}, two things must be done:

(a) the relationship between torque current I_T and acceleration must be determined to find torque current at constant high speed $I_{T,\ CONSTANT\ HIGH\ SPEED}$, and
(b) the relationship between torque current at constant high speed $I_{T,\ CONSTANT\ HIGH\ SPEED}$ and compensation frequency f_{comp} must be learned.

(A) Relationship between I_T and Acceleration

The torque current I_T is not obtained directly but it may be obtained approximately by measuring the real component of the stator current when the angle between the stator voltage and flux is nearly 90 degrees.

Fig. 2 is a block diagram illustrating the invention. A motion control 2 provides a reference stator frequency f_{ref} to a summer 4 where f_{ref} is added to a compensation frequency f_{comp}, which is zero until it is provided by a profile adder 6 at the end of motor jerk-out. From the summer 4, a compensated reference stator frequency f_{cref} is applied to a frequency to voltage converter 8 where a compensated stator frequency input f_{cref} determines a stator voltage output Us. The compensated reference frequency f_{cref} is also applied to a pulse width modulation inverter (PWMI) 9 including a pulse-width-modulator (PWM) 12 and an inverter 14. The transfer function of the frequency to voltage converter 8 is shown in Fig. 1. The frequency to voltage converter 8 provides the stator voltage Us to the PWMI 9.

The PWMI 9 provides an angle phi. The angle phi may be obtained by integrating the stator frequency f_{ref} to the inverter 14 with respect to time. This gives a reference angle phi, but not the actual angle. The actual angle phi is the angle that the stator voltage U_S makes with the real axis as U_S rotates at a speed ωt, where ω is the angular frequency of rotation. A reference angle phi, rather than the actual angle phi, is obtained this way because it is obtained by integrating a reference value--the reference stator frequency f_{ref}.

The actual angle phi may be calculated as the sum of an original angle ϕ_o and a differential angle $\Delta\phi$,

$$\text{where } \Delta\phi = \frac{f_{cref} * 360 \text{ degrees}}{2 * \text{switching frequency of the inverter.}}$$

The original angle is the angle during the last control cycle of the inverter 14; one control cycle of the inverter 14 is equal to 1/(switching frequency of the inverter). When the motor is starting this angle is zero.

The PWMI 9 also provides three inverter Iu, Iv, Iw stator currents to an IM 13 which can turn a sheave 14 and move a car 15 and a counterweight 16.

Two current sensors 18 measure two inverter stator currents Iu, Iv, and provide them to a sample and transformation means 20. The angle phi is also provided to the sample and transformation means 20. An acceleration reference A_{ref} is provided by the motion control 2. A_{ref} can also be provided by sampling and differentiating f_{cref} with respect to time. The sample and transformation means 20 samples the two inverter stator currents Iu, Iv. The sample and transformation means 20 samples in response to a jerk-out signal provided by the motion control 2 at the beginning of the first jerk-out segment C (Figs. 3 and 4) and ceases sampling in response to a no jerk-out signal at the end of that jerk-out region.

The sample and transformation means 20 provides A_{ref} and the real component of the stator current Rel to a linear regression means 22. The linear regression means 22 calculates an equation of a line relating A_{ref} and Rel in the form y = mx + b, where b is the y intercept of that line, and physically represents $Rel_{CONSTANT\ HIGH\ SPEED}$, the real component of the stator current Rel at a high constant motor speed (represented by point "d" on Figs. 3 and 4). $Rel_{CONSTANT\ HIGH\ SPEED}$ is provided to a compensation means 24. The relationship between $Rel_{CONSTANT\ HIGH\ SPEED}$ and the compensation frequency f_{comp} may be described by a linear equation. The compensation means 24 provides a compensation frequency f_{comp} to the profile adder 6, where a profile is provided by the motion control 2 for smoothly adding the compensation frequency f_{comp} to the reference frequency f_{ref} at the summer 4.

Fig. 3 is a graph of torque current I_T v. A_{ref}, a reference acceleration. Relating movement of the IM 13 to the graph, the IM 13 is at standstill at a point "a". The standstill point "a" represents both the beginning and ending point. The vertical axis of Fig. 3 is the torque current I_T, which is approximately equal to the real component of the stator current Rel when the IM

13 is running at high speeds. Current torque I_T is, in turn, proportional to slip. When the IM 13 begins moving, jerk is a positive constant value, the IM 13 accelerates along segment A until point "b" is reached. Where the IM 13 turns the elevator sheave 14 for moving a car 15 and counterweight 16, the torque current I_T at point "a" is the value required to balance the car 15 with the counterweight 16.

Segment A is known as jerk-in because a positive jerk is applied to the IM 13. The IM 13 reaches maximum acceleration at point "b". The difference in torque current I_T between point "b" and point "a" is the torque current I_T responsible for acceleration torque plus torque current I_T responsible for friction torque. Acceleration torque is the torque required to accelerate the IM 13. Friction torque is the torque applied to the IM 13 to overcome friction.

The IM 13 then constantly accelerates between points "b" and "c" along segment B, at maximum acceleration. During this time, jerk is zero. In response to a negative jerk applied when the IM 13 is at point "c", the IM 13 accelerates at a lower rate in a segment C, called jerk-out because the IM 13 experiences a negative jerk there. The difference in torque current I_T between "b" and "c" is the torque current I_T required to overcome additional friction because the speed of the motor increases between "b" and "c". So long as there is speed in the IM 13, there is friction torque.

At point "d", the IM 13 moves at constant speed and therefore experiences zero jerk. A constant speed point "d" is shown on the graph of Fig. 3 here, but it is not necessarily true that a motor will always move at a constant speed during a velocity profile. Point "d" marks the point at which the car 15 is positioned approximately halfway between the beginning and ending points "a" and a velocity profile of the car.

The IM 13 leaves point "d" and experiences a negative jerk on segment D as it decelerates to point "e". Between points "e" and "f" on segment E, the IM 13 moves at constant acceleration while the torque current I_T decreases. The jerk is zero. The torque current I_T between points "d" and "e" decreases in order to decelerate the IM 13 and overcome gradually less friction. When the IM 13 again experiences jerk-out, the IM 13 moves from point "f" to point "g" along segment F as the acceleration A_{ref} becomes less negative. The current torque I_T between points "f" and "g" represents the current torque I_T required to overcome friction and decrease acceleration of the IM 13.

From point "g", the acceleration decreases suddenly, then remains constant, and finally increases until the stopping point is reached at point "a". The difference in current torque I_T between points on segment G represents the current torque I_T required to reduce friction encountered by the IM 13 from the friction as the car 15 moves from creep speed to standstill.

As can be seen from Fig. 3, segments A and F are concave up slightly, and segments C and E are concave down slightly. The cause of the nonlinearity is that the relationship between friction in the IM 13 (and the torque required to overcome it) and acceleration is nonlinear, although friction is linear with respect to speed. In addition, the behavior of the IM 13 is nonlinear. Accordingly, the amount of curve depends on the amount of friction in the motor drive system, especially in the gears turned by the IM 13; if the friction in the selected motor drive is low, segments A, F, C, and E will be even more nearly linear than in Fig. 3. For the purposes of the invention, segment "C" is considered to be a straight line.

Fig. 4 is a graph of time v. speed reference f_{ref}, acceleration A_{ref} (m/sec^2), jerk (m/sec^3), and actual speed (m/sec). The points (a-g) and segments (A-G) correspond to the points and segments on the graph of Fig. 4. The IM 13 starts from zero speed during segment A, begins moving, and experiences a jerk and an acceleration until the IM 13 reaches point "b". During segment B, speed continues to increase, the acceleration is constant, at a maximum and the jerk is zero. During segment C, the speed continues to increase but the acceleration is decreasing and the jerk is negative. At "d", the speed is constant, the acceleration is zero, and the jerk is zero. During segment D, the jerk is negative, the speed is decreasing, and the acceleration is decreasing. During segment E, the speed is decreasing, the acceleration is at a negative maximum, and the jerk is zero. During segment F, the speed is decreasing, the acceleration is increasing, and the jerk is positive. At point "g", the IM 13 moves at a constant creep speed until a leveling signal is received by the motion control 2, at which point the IM 13 speed begins ramping down to zero in segment G. After the level signal is received by the motion control 2, the acceleration A_{ref} is negative for the purpose of stopping the IM 13.

In Fig. 4 the actual speed for a fully loaded IM 13 is shown. The actual speed differs from the reference speed f_{ref} in that (a) there is a speed error during the creep region, and (b) the level signal is provided much later for the actual speed than for the reference speed, and creep time (the time during which the car 15 is moving at creep speed) is longer.

Fig. 5 shows a stator current I vector, a flux vector, torque current I_T and magnetization current I_{mag} for a VVVFIM. The coordinate system is a synchronous reference frame, meaning that the stator voltage always lies on the real axis and the coordinate system rotates with a frequency ωt. The angle gamma between the stator voltage U_S and stator current I does not depend on whether the reference frame of Fig. 4 rotates in synchronism with the frequency of the stator voltage or whether it is fixed. The stator current I is the vector sum of the magnetization current I_{mag} and the torque current I_T. Fig. 5 represents the stator current I when the IM 13 is running at high speed and

the angle between the flux and stator voltage U_S is nearly 90 degrees such that the real component of the stator current I is nearly equal to the torque current I_T. Given that, and the fact that the torque current I_T cannot be measured directly, the torque current I_T can be measured approximately by measuring the real component of the stator current I.

Fig. 6 is a flow chart of the sample and transformation means 20. Fig. 6 shows a loop. The number of iterations of the loop equals the number of times Iu, Iv, and phi are sampled and also the number of values of Rel provided to the linear regression means 22. Iu, Iv are measured (step 1), the angle phi obtained from the PWMI 9 (step 2). Then two values sin 1 = sin(Π/3 -phi) and sin 2 = sin(phi) are obtained from a lookup table (step 3). In step 4, the real component of the stator current, Rel is calculated:

$$\mathrm{Rel} = \frac{2}{\sqrt{3}}\left(I_u \sin 1 - I_v \sin 2\right)$$

For each iteration of the loop, Iu, Iv and phi are sampled and a value of Rel is obtained and stored (step 5) until all calculated values of Rel are provided to the linear regression means 22 (step 7). Then, f_{comp} is added to f_{ref} smoothly at the end of motor jerk-out at point "d" of Fig. 4 in the profile adder 6 to provide the compensated reference frequency f_{cref}.

In Fig. 7, a magnet 26 on a hoistway wall 28 is sensed by a level sensor 29 and a level signal provided to the motion control 2 to indicate that the car 15 is at the creep zone and the motion control 2 should provide the value of f_{ref} which should be a creep speed value so that the car 15 can level with the door 30.

Relationship between $I_{T,CONSTANT\ HIGH\ SPEED}$ and f_{comp}.

The measurement of Rel is done at a high speed. But it is necessary to compensate at creep speed in order to provide the proper motor torque at creep speed, accurately position the motor near its stopping point, and compensate for speed error in the creep region. Therefore, a relation between f_{comp} at creep speed and the measured $\mathrm{Rel}_{CONSTANT\ HIGH\ SPEED}$ is needed. This is learned by carrying out a calibration scheme.

If instead of a relation between f_{comp} at creep speed and the measured $\mathrm{Rel}_{CONSTANT\ HIGH\ SPEED}$, a relation between f_{comp} at creep speed and I_T were used to generate f_{comp}, the value for f_{comp} would include error due to the fact that I_T is not provided by the linear regression means 22 using measured current values I_u, I_v. Providing f_{comp} from a relation between f_{comp} at creep speed and the measured $\mathrm{Rel}_{CONSTANT\ HIGH\ SPEED}$ rather than a relation between f_{comp} at creep speed and Rel ensures that the motor torque provided at creep speed will not include the larger friction torque found at high motor speeds. The calibration run also corrects the difference between the friction at point "d" and that at point "g". This is important because the torque current at constant speed obtained as a result of the linear regression is not the same value as that for low speed. In addition, generating f_{comp} from this relationship accounts for constant errors and load proportional errors in the measured current.

The relationship between $I_{CONSTANT\ HIGH\ SPEED}$ and compensation frequency f_{comp} is obtained on four calibration runs. Four calibration runs are made: two to obtain two $\mathrm{Rel}_{CONSTANT\ HIGH\ SPEED}$ values of waveform 1 of Fig. 8, and two to obtain two f_{comp} values. The two runs to obtain f_{comp} values are made with f_{comp} initially set to zero and the IM 13 running at creep speed because it is the creep speed error that is desired to be eliminated. Fig. 8 shows f_{comp} v. $\mathrm{Rel}_{CONSTANT\ HIGH\ SPEED}$. The top and bottom margins are the maximum allowed slip.

The two runs to obtain high speed values are made with the IM 13 running at high speed because that is the speed the IM 13 will be running at when Rel is determined during jerk-out. On the first calibration run, the IM 13 is run with no load at creep speed with the car 15 moving in the down direction to get the f_{comp} for motoric conditions. On the second run, the IM 13 is run with the car 15 moving in the up direction to get the f_{comp} for generatoric conditions. Moving the car 15 down is a motoric condition because the counterweight 16 is heavier than the car 15 with no load in it. Moving the car 15 up is a generatoric condition for a similar reason. These two runs consist of moving the car 15 and counting the number of sheave revolutions per unit time. If this number differs from f_{ref}, with f_{comp} set to zero, then a calibration signal from a function generator is provided to the summer 4 and adjusted until the number of sheave revolutions per unit time equals $f_{cref}/(P*i)$. On the third calibration run, the IM 13 is run at high speed down to get $\mathrm{Rel}_{CONSTANT\ HIGH\ SPEED}$ for motoric conditions. On the fourth run, the IM 13 is run up at high speed to get the $\mathrm{Rel}_{CONSTANT\ HIGH\ SPEED}$ for generatoric conditions. When no more adjustment to the value of the calibration signal are needed to make it equal to $f_{cref}/(P*i)$, that value of the calibration signal is equal to f_{comp}.

Fig. 9 shows A_{ref}, V_{car} (the velocity of the elevator car which is proportional to f_{cref}) and V_{ref} (the dictated velocity which is proportional to f_{ref}) with and without compensation. The difference D between V_{car} and V_{ref} is constant from the time f_{comp} is applied until the end of the creep region except for when f_{comp} is first added smoothly to f_{ref}.

Claims

1. A method of compensating for a difference between a reference frequency proportional to a dictated motor speed and actual motor speed in

an open loop three phase asynchronous motor drive, comprising:

providing a reference acceleration signal during motor jerk out;

measuring the real component of a stator current;

obtaining a constant speed value from the real component of the stator current; and

providing a compensation frequency which is a function of the constant speed value; and

adding said compensation frequency to said reference frequency.

2. The method of claim 1, wherein said real component of the stator current is measured by measuring two stator currents, measuring an angle phi between the phases of the stator flux and stator voltage, calculating two values sin 1 = sin(Π/3-phi) and sin 2 = sin(phi), and calculating the real component of the stator current, according to the equation:

$$\mathrm{Rel} = \frac{2}{\sqrt{3}} (I_u \sin 1 - I_v \sin 2).$$

3. The method of claim 1 or 2, wherein said compensation frequency is added at the end of motor jerk out.

4. The method of claim 1, 2 or 3 wherein said step of providing a compensation frequency includes the steps:

(a) moving the motor in a first direction with no load on the motor, while said reference frequency is set to a creep value and said compensation frequency is zero, summing a calibration signal with said reference frequency and adjusting the magnitude of said calibration signal until it is proportional to the rotor speed and providing a compensation frequency signal for a motoric condition;

(b) moving the motor in a second direction with no load on the motor, while said reference frequency is set to a creep value and said compensation frequency is zero, summing a calibration signal with said reference frequency and adjusting the magnitude of said calibration signal until it is proportional to the rotor speed and providing a compensation frequency signal for a generatoric condition;

(c) moving the motor in said first direction with no load on the motor, while said reference frequency is set to a high speed value, and measuring a constant value for a motoric condition;

(d) moving the motor in said second direction with no load on the motor, while said reference frequency is set to a high speed value and measuring a constant value for a generatoric condition;

(e) obtaining said constant speed value;

(f) substituting said constant speed value into an equation of a line defined by said compensation frequency signal for a motoric condition, said compensation frequency signal for a generatoric condition, said constant value for a motoric condition, and said constant value for a generatoric condition and obtaining a compensation frequency.

5. A speed compensator for an open loop asynchronous motor drive responsive to a reference frequency proportional to a dictated motor speed, comprising:

sample and transformation means for providing the real component of a stator current in response to two phase stator currents and an angle between a stator voltage and a real axis;

linear regression means, responsive to said real component of said stator current for providing a constant speed value of said real component of said stator current;

compensation means, responsive to said constant speed value for providing a compensation frequency; and

a summer for adding said compensation frequency to said reference frequency.

6. The speed compensator of claim 5, wherein the relationship between said compensation frequency and said constant speed value is described by a linear equation.

7. The speed compensator of claim 5 or 6, wherein said compensation frequency is added at the end of motor jerk out.

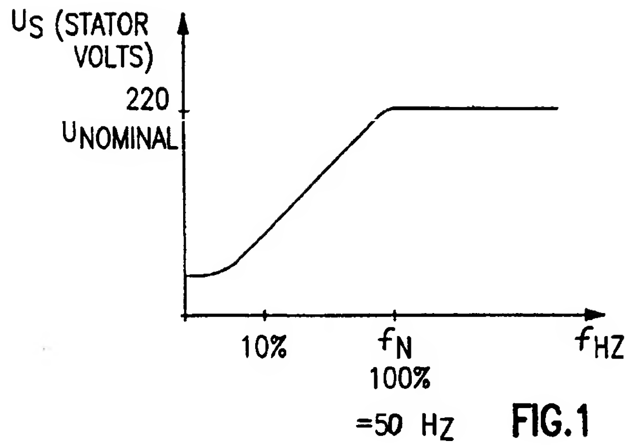

FIG.1

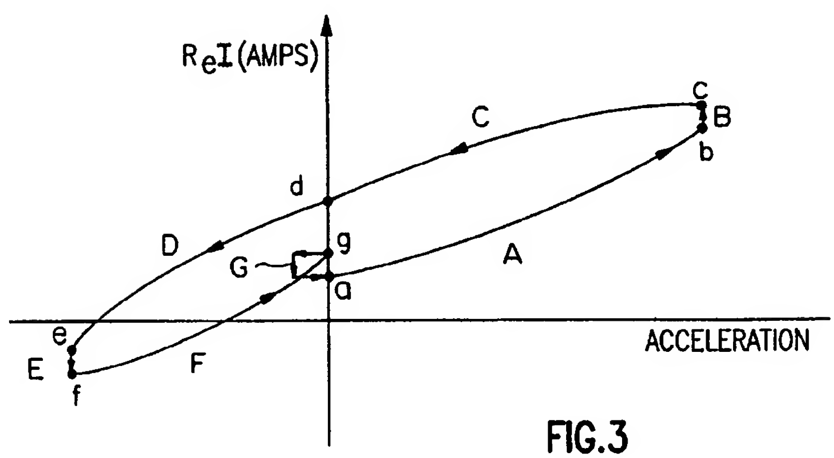

FIG.3

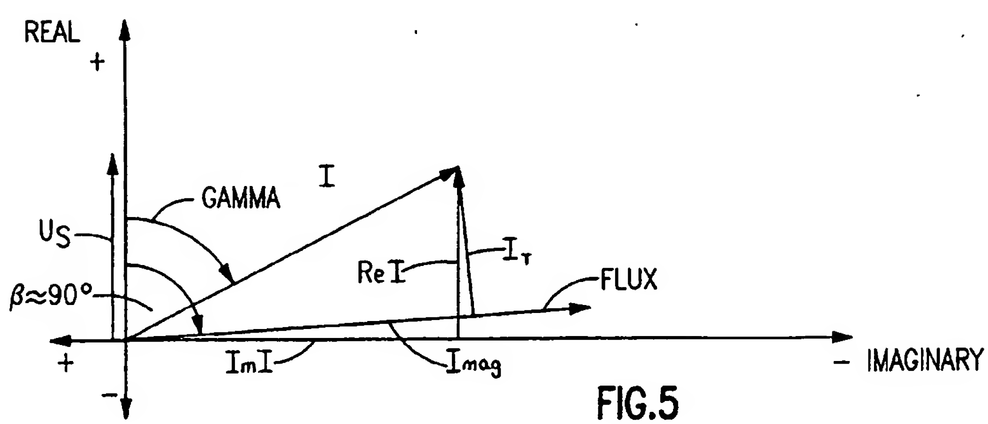

FIG.5

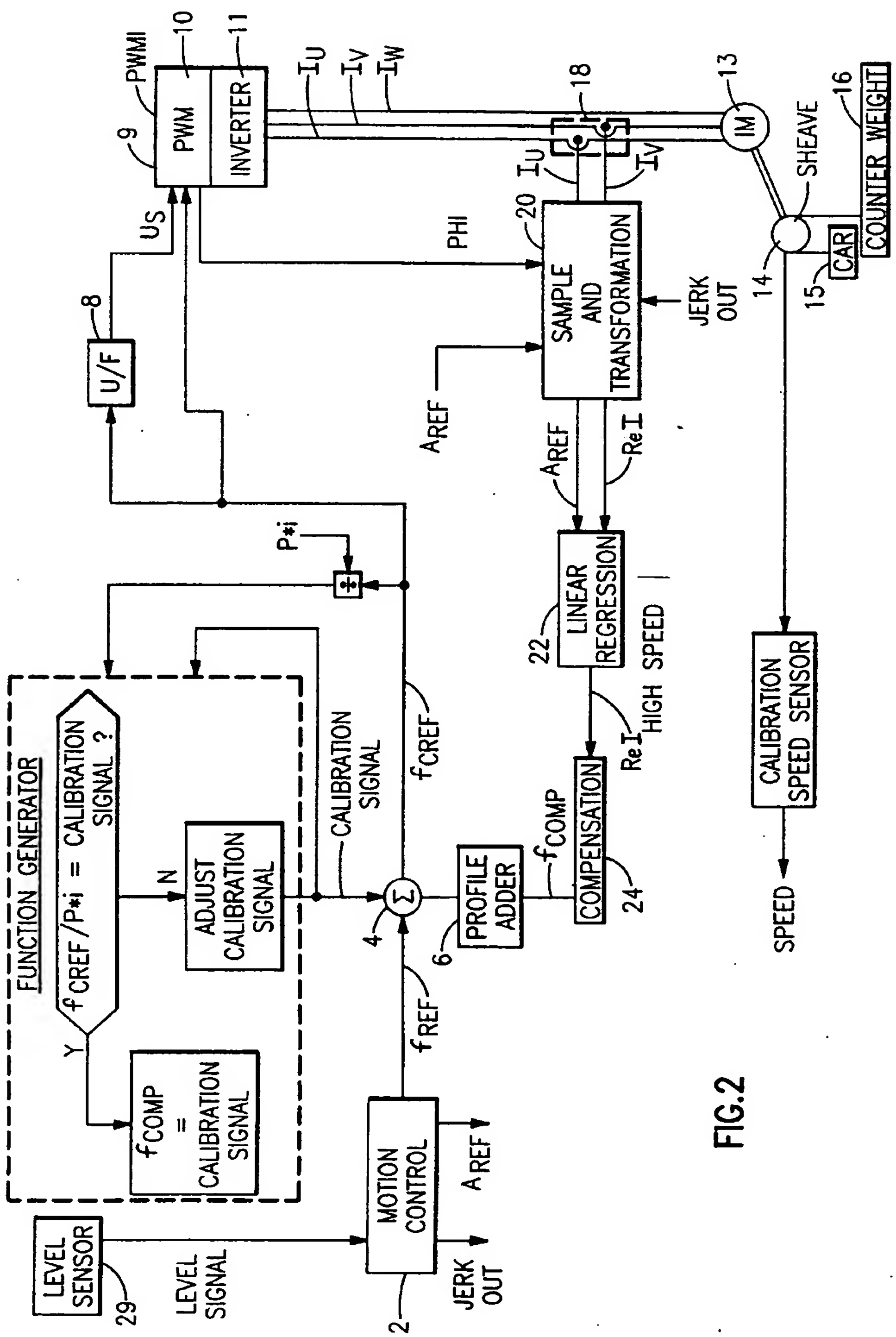
PWMI
PWM
INVERTER
9
10
11
I_U
I_V
I_W
U/F
8
U_S
PHI
SAMPLE AND TRANSFORMATION
20
18
I_U
I_V
IM
13
SHEAVE
14
CAR
15
COUNTER WEIGHT
16
JERK OUT
A_{REF}
A_{REF}
Re I
LINEAR REGRESSION
22
HIGH SPEED
Re I
COMPENSATION
24
f_{COMP}
CALIBRATION SPEED SENSOR
SPEED
P_{*i}
÷
FUNCTION GENERATOR
f_{CREF}/P_{*i} = CALIBRATION SIGNAL ?
Y
N
f_{COMP} = CALIBRATION SIGNAL
ADJUST CALIBRATION SIGNAL
CALIBRATION SIGNAL
f_{CREF}
Σ
4
PROFILE ADDER
6
f_{REF}
LEVEL SENSOR
29
LEVEL SIGNAL
MOTION CONTROL
2
JERK OUT
A_{REF}

FIG.2

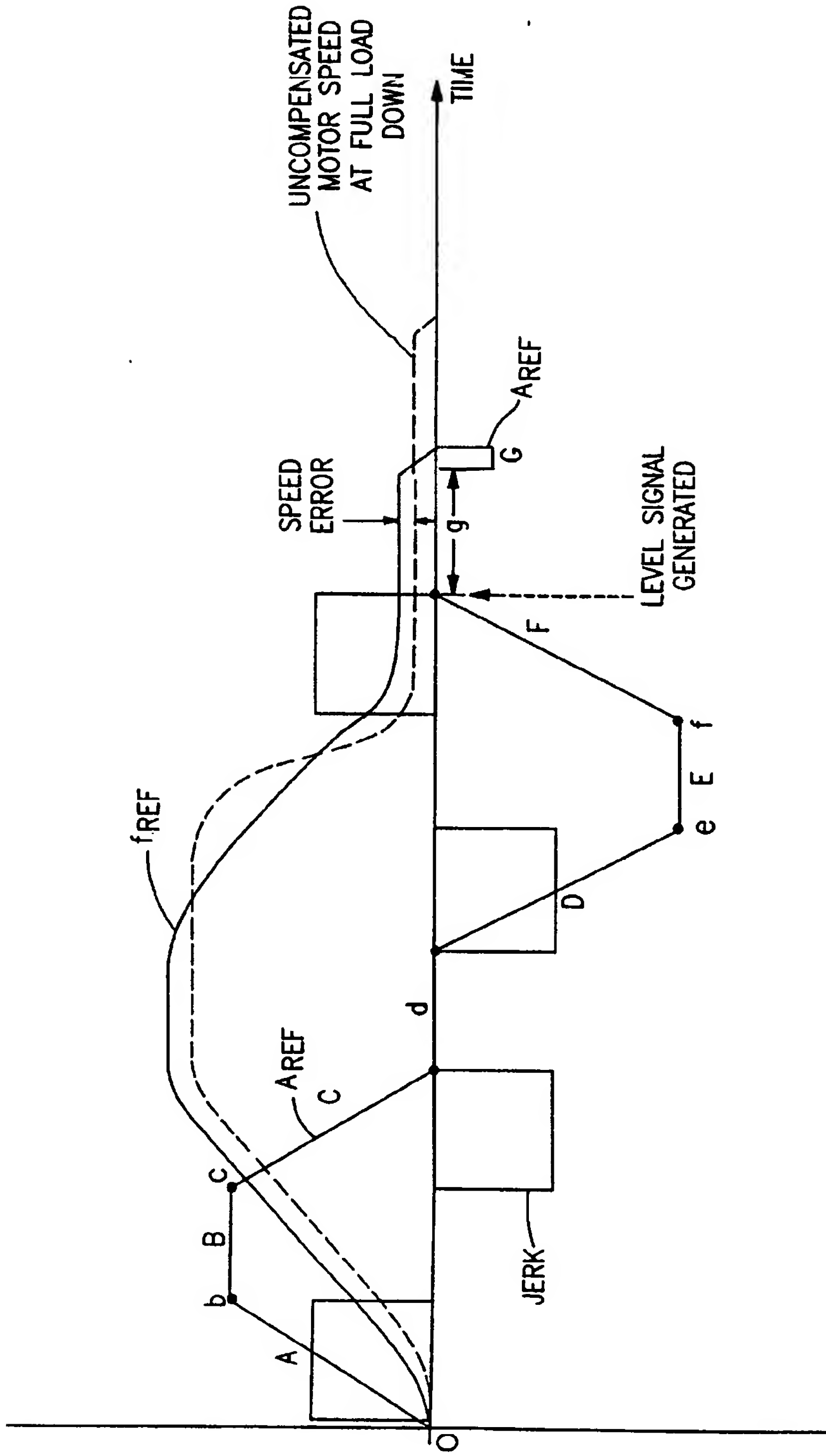
UNCOMPENSATED
MOTOR SPEED
AT FULL LOAD
DOWN
TIME
SPEED
ERROR
LEVEL SIGNAL
GENERATED
AREF
G
g
F
f
E
e
D
d
fREF
AREF
C
c
B
b
A
JERK
O

FIG.4

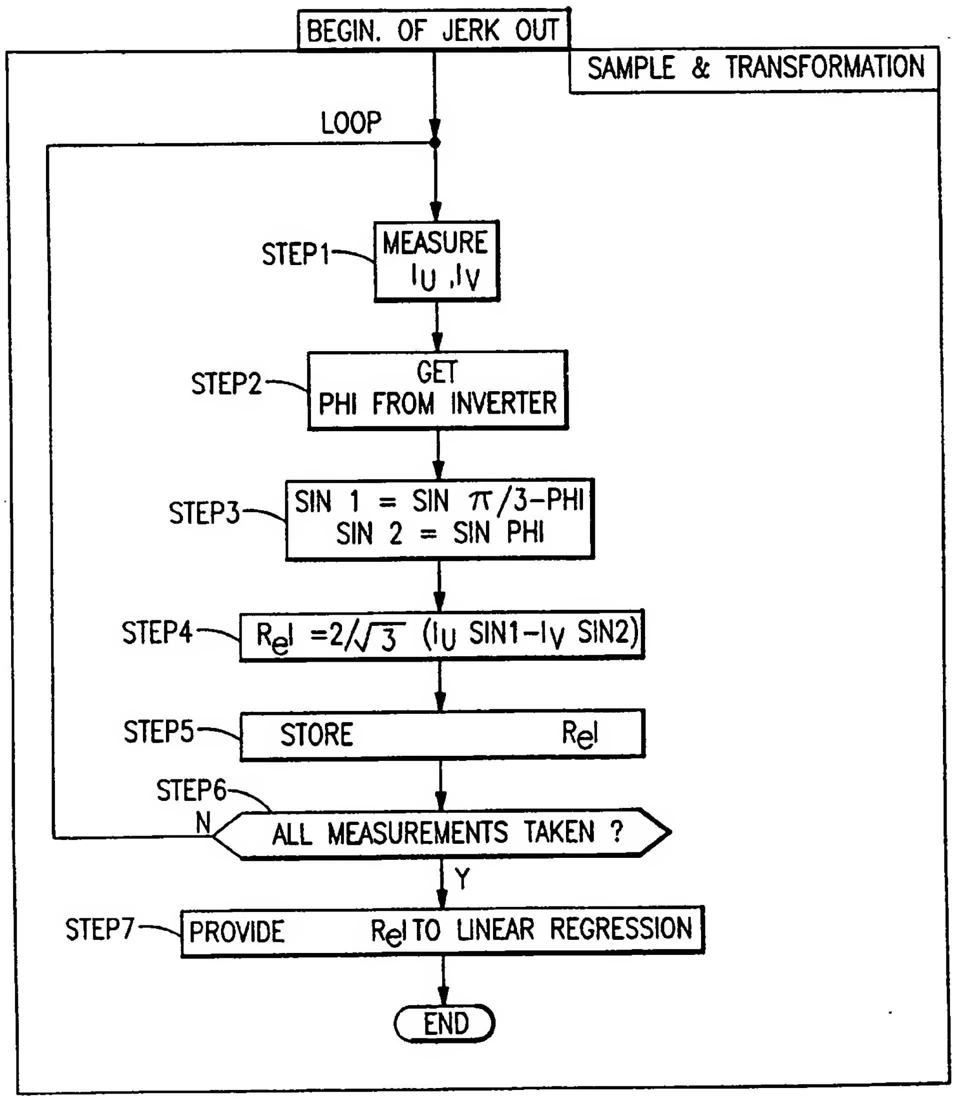
BEGIN. OF JERK OUT
SAMPLE & TRANSFORMATION
LOOP
STEP1
MEASURE
IU ,IV
STEP2
GET
PHI FROM INVERTER
STEP3
SIN 1 = SIN π/3-PHI
SIN 2 = SIN PHI
STEP4
Rel =2/√3 (IU SIN1-IV SIN2)
STEP5
STORE Rel
STEP6
N
ALL MEASUREMENTS TAKEN ?
Y
STEP7
PROVIDE Rel TO LINEAR REGRESSION
END

FIG.6

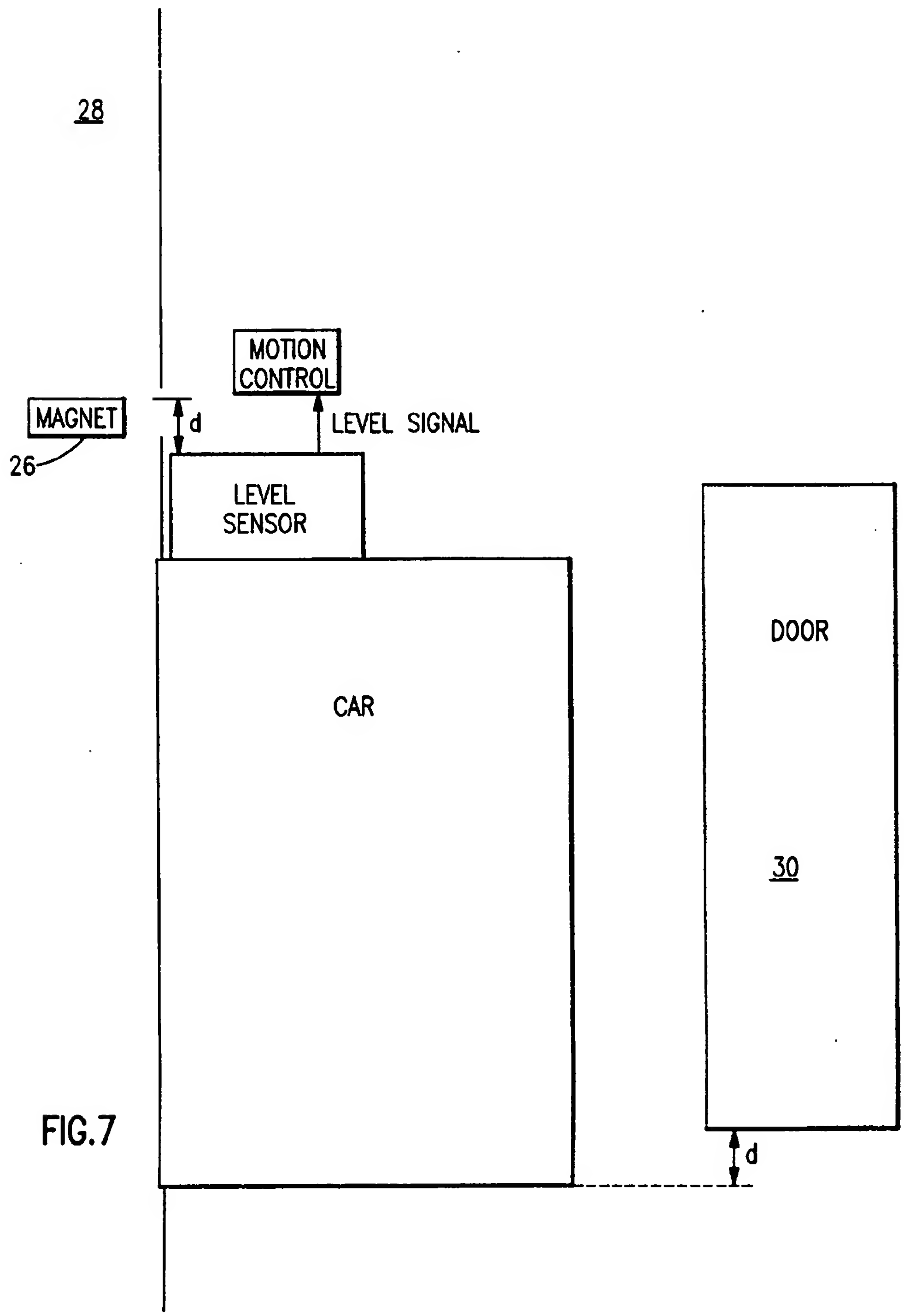
28
MOTION CONTROL
MAGNET
d
LEVEL SIGNAL
26
LEVEL SENSOR
DOOR
CAR
30
d

FIG.7

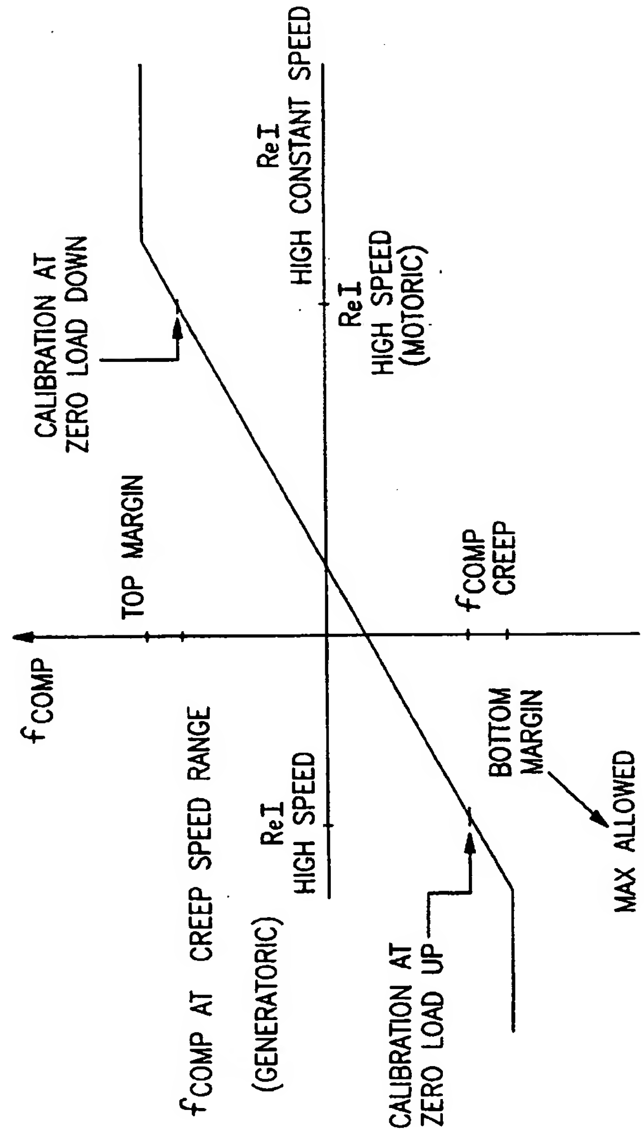
fCOMP
TOP MARGIN
CALIBRATION AT ZERO LOAD DOWN
ReI HIGH CONSTANT SPEED
ReI HIGH SPEED (MOTORIC)
fCOMP CREEP
BOTTOM MARGIN
MAX ALLOWED SLIP
fCOMP AT CREEP SPEED RANGE
(GENERATORIC)
ReI HIGH SPEED
CALIBRATION AT ZERO LOAD UP

FIG.8

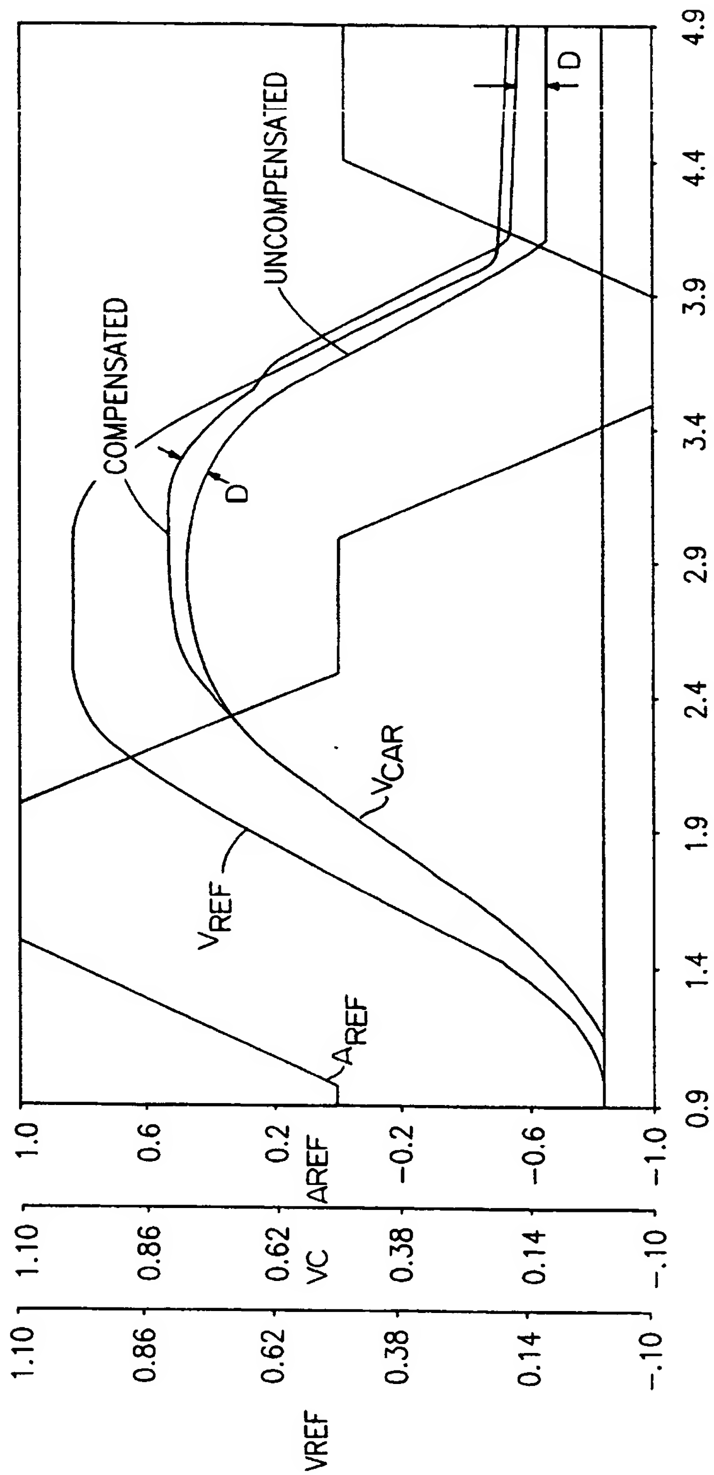
COMPENSATED
UNCOMPENSATED
D
D
V_{REF}
V_{CAR}
A_{REF}
1.0
0.6
0.2
AREF
−0.2
−0.6
−1.0
1.10
0.86
0.62
VC
0.38
0.14
−.10
1.10
0.86
0.62
0.38
0.14
−.10
VREF
0.9
1.4
1.9
2.4
2.9
3.4
3.9
4.4
4.9

FIG.9

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 30 4636

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	EP-A-0 423 384 (OTIS ELEVATOR COMPANY) 24 April 1991 * column 2, line 42 - column 3, line 8 * ---	1,2	H02P7/62 B66B1/06
D,A	US-A-4 982 816 (DOI ET AL.) 8 January 1991 * abstract * ---	1	
A	EP-A-0 335 599 (OTIS ELEVATOR COMPANY) 4 October 1989 * abstract * ---	1	
D,A	US-A-3 619 750 (BORIS MOKRYTZKI) 9 November 1971 ---	1	
A	PATENT ABSTRACTS OF JAPAN vol. 015, no. 171 (M-1108)30 April 1991 & JP-A-30 36 177 (NIPPON OTIS ELEVATOR CO) 15 February 1991 * abstract * -----	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			H02P B66B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	09 SEPTEMBER 1993	BOURBON R.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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E : earlier patent document, but published on, or after the filing date
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